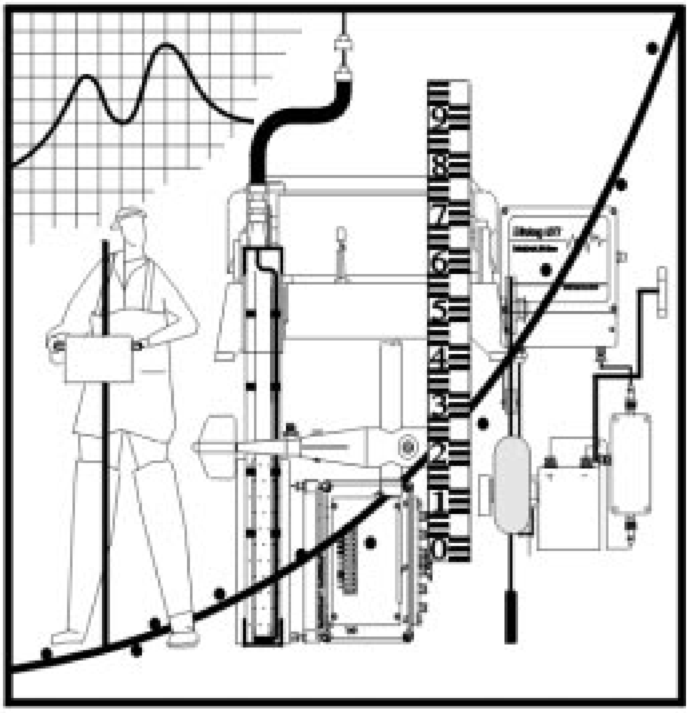
HYDROMETRY QUALITY CHARTER

GUIDE TO GOOD PRACTICES



BANQUE HYDRO

MINISTERE DE L'ENVIRONNEMENT

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INTRODUCTION

In this age when IT is king and sophisticated computer modelling is common place, is there still a place for low tech science such as hydrometry ? Is this merely a costly use of manpower and time, yielding only marginal gains in productivity, requiring sophistic justification, of limited interest in a period of increasingly rare money?

We've got to take a stand: the overwhelming majority of mathematical models err in their calibration data. Today it is less expensive to create a model than to go out into the field and collect real data. If we scratch beneath the surface of some of these hydrological projects- and certain recent scientific committee opinions remind us of this- we can quickly see the problem and underline the extent to which derived default hypotheses can have consequences not only in terms of risks but also in terms of possible cost overruns.

The use of hydrological data is growing rapidly. Beyond the needs for modelling purposes, water use regulations have pushed us to better judge the effect of projects in observing an area and subsequently its fluctuations. Finally, the development of irrigation, using an increasing portion of seasonal discharges, made it necessary to manage this water use, which meant a better real time understanding of discharges.

The quality charter, created by the HYDRO database user committee, shows that the hydrometry techniques have greatly evolved over the last fifteen years. There has always been an overriding concern for traceability, so that tomorrow's enlightened critics will be able to obtain current as well as historical data.

In this charter, several improvements have been planned in order to ensure a maximum quality for hydrological data. It is therefore an everyday work guide whose vocation is to serve as a commitment to quality for hydrometry services.

The originality of this charter, then, is that it is designed firstly for field personnel, although technicians and engineers will surely find some interesting surprises herein, and there is even something for the decision makers and financial experts whose curiosity takes them beyond the realm of educational illustrations.

The Director

P. ROUSSEL

" THE PROBLEM OF MEASURING DISCHARGES IS CURRRENTLY ONE OF THE MOST AGREVATING OF SCIENTIFIC UNCERTAINTIES"

L. BARBILLON 1909

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FROM RAW MEASUREMENTS TO VALIDATED DISCHARGES: MAIN ERROR FACTORS

All along the chain of hydrometric data processing, from the raw measurements in the field to the validation of discharge, there are a number of recurrent errors which occur and which we should concentrate on reducing. Methodological rigor will allow us to obtain consistently reproducible and satisfactory results.

In fact, a quality approach doesn't mean concentrating all of our attention one particular factor but rather eliminating the main causes of error, then using the recommendations of the good practices guide which are set out in the following chapters.

At the risk of being obvious, we will first present some major error factors. Our experience has lead us to observe that every hydrometrist has at one time or another made a major mistake. Distance is sometimes necessary for us to evaluate our practices. We hope that this guide, which is intended for everyone, will be useful for developing high quality hydrometry.

1-For Gauging, measure the entire discharge.

A backwater discharge forgotten in high water conditions, a partially obstructed (and thus unmeasured) mill's runway in an urban zone, a secondary branch tangled in plant growth or other similar oversights can affect measurement results anywhere from 10 to 100% no matter what the discharge.

This inaccuracy could be even greater then errors made when determining discharges using floaters to measure water surface speed.
Measurement depends, then, on careful, meticulous field observations.

Also daily practices should include care attention to equipment maintenance and to the number and positioning of vertical gauges.

2- Often at a given site, only part of the recorded levels can be converted into discharge.

On some sites, because of downstream conditions such as a blockage or gates, the levels might only be valid when greater than a certain value.

At other sites, the opposite could be true: information might only be valid at lower levels, for example, when there is a backwash of a flooding tributary.

Still other sites could be affected by plant growth and require a greater number of gauges.

These site constraints should result in:
- a change in the site location, if possible
- if a change is not possible, strictly limiting high or low extrapolation on this sites curve data

It is not sufficient to continue using a site whose information does not meet quality criteria solely because that site has been providing discharge data for a long time.

3-The main uncertainty about rating curves- extrapolating discharges beyond measured values

The use of simple arithmetic or logarithmic extrapolation from the office is a practice used too often. Easy to use, these methods are dangerous because the results are often far too weak or too strong. Moreover, extrapolation based on an extreme measurement is fragile; the absence of measurement after overflow brings about estimations which could be highly erroneous. It would be more appropriate to insist on the fundamental role of real measurement.

A hydrologist's good knowledge of the area allows him to take a suitable approach to discharge measures and thus derive more reliable extrapolations.

Methods of fine tuning estimations at high discharges include: 1) making a cross profile which allows extrapolations from average speed and wetted section; 2) taking into account the geometric characteristics of measuring sites and their control sections (high flow channel). These can also be useful in setting up a small model. This fundamental work, when it is done, has a significant impact on the outlying values of high water measurements. This approach is always more reliable than "office extrapolation".

4- General conception

Hydrometry is not a laboratory science; it should be done in the field. Dividing up the work into specialized tasks is not recommended. On the contrary, project leaders should be out in the field with their researchers, to understand the real political, motivational and material constraints present.
Hydrometry should not be just a routine but rather a profession open to technology, intelligence and re-evaluation.

GAUGING

1 PRELIMINARIES AND REMINDERS

There is no universal method for measuring water stream discharges. The choice of method is affected by various factors, among which are:

- the site configuration and flow conditions
- measuring equipment and available time
- the number of people participating in the measurement activity
- the degree of accuracy desired

For the precise determination of a discharge in natural conditions it is always preferable to have an actual measurement than to rely on the use of hydraulic formulas.

➢ MAIN METHODS

To measure the discharge in "natural" conditions (water streams, canals, derivations etc,) there are four main categories of methods.

• *Volumetric methods*, which allow the calculation of discharge based on elapsed time and volume of liquid run into a calibrated reservoir. Given the inherent practical aspects of this method (size of the reservoir, uncertainty about beginning and ending time and possible specific arrangements), it generally used in low discharge conditions, not more than a few l/s. Nonetheless, we can point to the use of floodgates or water runways in certain cases for specific measurements.

• *velocity - area methods* - these consist of determining the water flow speed at different points of the section while measuring the surface area of the wetted section. Besides the current meter method, other techniques have been developed in recent years. Each requires specific equipment (current meters, sounding rods, perch, sounding weight, etc.) as well as specially trained personnel.

• *Hydraulic methods* depend on the relations between forces which control the flow (weight, inertia, viscosity, etc.)

• *Physical methods*, which take into account variations during water flow due to various physical properties of liquids, for example, concentrations of certain dissolved elements. Generally, this method involves injecting a solution into a stream and monitoring its evolution and its concentration over time. Sometimes this is known as the "dilution" or "chemical" method.

1.2 BASIC PRINCIPLES

Now we should define, regardless of the method used, some of the most important basic principles.

To start with, **we must be sure that we are measuring the entire discharge.** To do this, we must first have a 1:25000 scale topographic map, if the area has never before been used as a point of measure. This map will allow us to establish the site's configuration, especially at the level where the measurement will be taken, the number of measuring arms necessary and site accesses.

Then, field verification is done to verify the accuracy of the map. This allows us to precisely fix the location of the measuring section, to decide what materials are best, as a function of width and depth of stream bed, estimated flow speed, the time needed for the measurement and also to plan for safety and other particular constraints.
In the field, do not hesitate to move upstream or downstream (even hundreds of meters, if necessary) to find a measuring section which has the characteristics best suited to the chosen method of measure. In that case we need to check for losses or gains which occur between the location where we originally wanted the measurement and the location where the measurement is actually made. These losses or gains should be measured or estimated. Likewise we must integrate the difference of phase of the wave propagation in order to define the related water level of the gauging.
In the case where there is not only one section but several (which happens often in high water conditions), all the tributaries contributing to the flow must be measured. Each measure is thus independent (different methods may be applied to each tributary) the total discharge being the sum of all the partial discharges measured.

Overlooking a branch or a back water tunnel of a river is one of the leading causes, if not THE leading cause of error in making flow measurements

Also, **be sure that the water level does not vary significantly during the measurement,** in other words not more than 1 cm at low flow, or 3-5 cm at high water. You must note the water level at the beginning, during, and at the end of the measuring period, using a fixed and stable reference point, i.e., a bridge pylon, a marked stake, painted rock, etc.). When the water level varies rapidly, intermediate height measurements are practical.

The height of the gauging reference can be determined as follows:

$$H = \frac{\Sigma\, hi\, qi}{\Sigma\, qi}$$

H= average level of gauging
hi= level of scale corresponding to partial discharge qi
qi= partial discharge, the product of a single discharge point calculated on the nth vertical by an application width
Q= Σ qi discharge calculated at level H

This formula is not absolutely rigid but it is well adapted to the real measuring conditions.

Stream gauging, in addition to the characteristics of measurement is distinguished by a precise location, a date, a beginning and ending time, and the most accurate notations possible about water level.

For reasons of data quality and security, **all discharge measurements, like all activities where there is a risk of drowning, must be performed by at least two persons, one of whom must be considered experienced.** Of course, for low flow measurements in small, shallow, slow moving streams, one person will probably be sufficient. Also to be taken into account are bottom conditions, the occurrence of floodways, etc. In the case of large waterway gauging involving the use of boats, suspended cable or anchored systems, etc., it is highly recommended that three persons be present, the third to ensure preparations such as road signalisation or to help with unexpected developments. In any case, one person should stay on the bank to provide first aid and call for help in the event of a serious accident.

With the development of white water sports such as canoeing and rafting additional risks have surfaced. A cable stretched across a stream or a sounding weight can present hazards for unknowing water sports enthusiasts. Information signs should be posted, warning recreational users of measuring activities and potential dangers along with other appropriate signalization (beacons, bell buoys, etc.)

Last, the **measuring equipment should be in good working order** (see current meter maintenance, P.9) and used by competent personnel with sufficient experience. Equipment use and temporary storage should always be in the best possible conditions.

2 STREAM GAUGING USING VELOCITY - AREA METHOD

2.1 CURRENT METER VELOCITY GAUGING

The principle of this method consists of determining a velocity field in a cross section of a stream and computing the discharge using known geometric relationships.

In reality, flow speed is never uniform in a given cross section of a stream. So it is a good idea to assess the velocity field in a number of different verticals spaced along its width. In addition, we get a profile of the cross section by taking a width measurement and depth measurements at several points of the cross section.

There are some recommendations regarding the measurement itself, the equipment used and the calculation of the discharge from the raw measurements taken. Keep in mind that stream gauging is made up of two phases: the first has to do with measurement the physical parameters (width, depth, speed); the second is the calculation of the discharge as a function of the recorded measurements.
The following recommendations are suggested to improve the accuracy of current meter gauging.

2.1.1 Choosing the measuring section

The geometric dimensions of the measuring section should be cleanly defined to cover all the streamflow .
This measuring section should be as rectilinear as possible. Its location should be far from natural or artificial obstacles or bends in the streambed. The measuring section should be perpendicular to the flow of the stream. When this is not possible, the widths of the biased section can be adjusted for correction.

The flow must be as regular as possible. Avoid taking measurements in converging or diverging flow areas that are oblique to the direction of the flow or that are in backwash or dead flow areas. If these conditions exist, try to estimate the amount of error caused. Some adjustment will then be made to the raw measurements.

The depth of the water should be sufficient that the equipment can be properly submerged. The measuring section itself should not present any disproportionate vertical or horizontal variation. In order to limit uncertainties, we are looking for the best compromise between sufficient depth and measurable water speed including low flow conditions.

The location of the section should not be obstructed by any obstacles immediately upstream or downstream (immersed tree trunks or branches, rocks, plant growths, etc.) which would affect the measurement. Small modifications may be made at the site of the measuring section as long as they do not affect the section where the limnigraph is situated e.g., building small dikes to channel water flow, cleaning up stones, roots or vegetation on the bottom and on the banks. In this case the measurement can be taken only after waiting enough time the stream flow has stabilised after modifications. All the same, if it is necessary to clean out moss or dead leaves with a sill, the measurement should be taken before the cleaning. Then, it would be a good idea to join up the discharge to the top water level after the cleaning (don't forget to wait for stabilization)

Remember: take enough time in choosing your measuring section. A badly chosen section will never yield a high quality gauging. The measuring section should stay the same in each type of discharge measure.

2.1.2 Equipment

Measuring equipment (cup or propeller style current meters) should be **adapted for the speeds** to be measured. Choose carefully the propeller in accordance with the ranges of speed expected to measure (pay attention to the manufacturers recommendations). In particular, the water speed should be sufficient to turn the propeller in good conditions. To limit uncertainty of the measurement, stream water speed should be greater than .05 m/sec for the most sensitive propellers. The propeller's pitch should be the lowest compatible with impulsion counter used. Likewise, the weight of the sounding weight should be adapted to the measuring conditions and water speed.

The weight and bulk of the measuring equipment are such that you must take care to set up its access and operation in the most ergonomic way possible.

Don't forget that the current meter/propeller/support assemblies should be tried out and calibrated in the lab. You must follow the calibrated configuration and avoid mixing and matching current meter parts that have not been calibrated together.

The equipment must be in good working condition, especially current meter axles, axle bearings, propellers as well as the propellers themselves. Also, don't hesitate to change often (ideally it should depend on the number of hours of use and the turbidity of the fluid) the oil ensuring the water tightness of the current meter. The propellers should not have worn or chipped blades. They should spin easily on the water meter axle without having to be tapped along. You should not be able to feel resistance to the rotation motion; stopping the rotation of a propeller should be as regular as possible and always happen in an easy natural way (this is easy to test). Moreover, on C31s, you can do a test called "back rotating the propeller" (a small reverse rotation after stopping).

CURRENT METER MAINTENANCE

Equipment maintenance begins with its storage. When transported it should be disassembled as much as possible or at least well blocked and protected to reduce vibrations. Also make sure that the propeller does not spin too much in the air.

Before each use, verify the propeller's condition.

After a campaign of measuring operations or one long measuring operation, change the oil.

C31 type current meter
Check and clean the axle and the bearings with white spirits (essence H) once a week. Using an ultrasound machine makes cleaning much easier.

If necessary, the bearings or axle can be replaced. Use white spirits to dissolve and eliminate the protective grease. These substitutions do not change the current meter's parameter .

C2 type meter
To clean the bearings, shake the axle/bearing assembly vertically in a bath of pure benzene.

After cleaning, during periods of nonuse, the parts should be stored without oil.

A careful check of the propeller/meter/impulsion counter assembly will allow you to verify its mechanical condition. Two check-ups per year would seem sufficient. It is just a matter of spinning the propeller and seeing how many rotations it makes before stopping. Then you examine the results on an abacus (see annex1).

It is fundamental to ensure a regular program of maintenance on the equipment and, replace, if necessary the propellers. If this is done, regular propeller recalibration becomes unnecessary.

Concerning impulsion counters, they should allow you to work point by point or in an integrated system. It would be wise to keep an extra set of batteries at hand so you don't have an electricity outage during "the gauging operation of the century". Likewise, particular care should be take with the electrical connections (cables, current meter, counter, etc.) Here also, don't forget to include in each vehicle, the spare parts necessary for each piece of equipment you carry.

For all of the support materials (graduated wading and sounding rods, winches, sounding weights, boats etc.), they should be properly maintained and stored in such a way that they will be operational even after relatively long periods (several months) of inactivity. The winch cable, the abscissa cable in case of a boat gauging operation, should be regularly checked for corrosion, rupture or twisting. This is an important aspect that should never be overlooked for it is a guarantee of safety and reliable operation for not only all of the data collection equipment, but also the personnel involved. Beams and ferry cables require specific maintenance. The normal standards regarding lifting machinery are not applicable to these systems.

This quality approach implies that there be a record which shows that equipment checks have been properly done.
We recommend, for example, that:
- visual propeller inspections be recorded at each gauging operation (see annex 3)
- oil changes and inspections of the propeller/meter/impulsion counter assembly be the object of checklist located in the current meter storage box and updated at each operation.

Lastly, the vehicle used to transport the men and equipment should be adapted for operations that need to be done and the distances that need to be covered. It should be sufficiently comfortable and practical to permit and even facilitate measuring operations. With this in mind, the signalization designed to protect the vehicle and its personnel should also be carefully maintained. Protective clothing, adapted for the elements as well as hip waders, should be replaced regularly. Finally, all vehicles should be equipped with a first aid medical kit.

Equipment problems should never get in the way of measuring operations. Equipment in good working order is indispensable. Extra equipment is necessary, especially in terms of consumables such as spare parts and parts which wear out. "Annex" equipment, which facilitates the measuring process, making it easier and more reliable is also one of the key elements for a successful measuring operation.
When faced with unexpected circumstances however, you may have to rely on more primitive less accurate methods of measurement. In a flood situation, it is better to obtain information of medium quality than no information at all.

2.1.3 Techniques

Without having to rewrite all the literature concerning the techniques of stream gauging (see bibliography), it seems important to recall some fundamental elements. These have to do with the choice of verticals, the number of points per vertical and the measuring time per vertical.

Gauging is a compromise between time of measure and precision of the measurement. The transportation time being generally longer than the actual measurement time, you must have an idea of what will be a sufficient amount of time to devote to the measuring operation. We will discuss gauging in flood conditions later.

The choice of verticals

Some people recommend that verticals be regularly spaced, others that the number of verticals be constant, no matter what width the stream, and others still, that verticals be spaced at variable intervals.

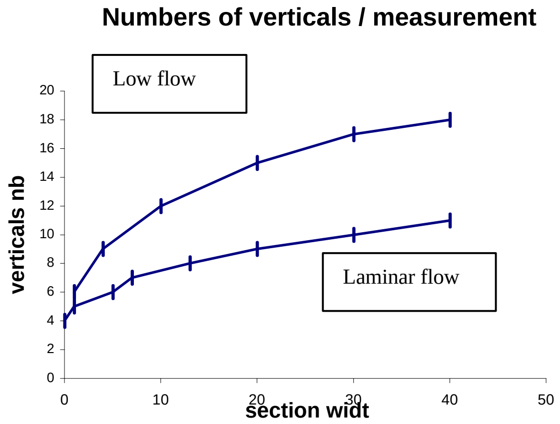
Vertical spacing should take into account the following principles:

- It is helpful to place verticals in a measuring section starting from a fixed point for each vertical such as a painted mark on a river bank or a reference point on a bridge. This makes it possible to compare stream gaugings and allows the discovery or explanation of rating curve shift from the movement in the streambed.
- It is a good idea to place the first and last verticals as close as possible to the limits of the section so as to minimize the influence of the riverbank coefficient.

An insufficient number of verticals usually leads to an under estimation of the discharge.

The spacing between each vertical should vary in a way that is inversely proportional to the variations in depth and water speed. **The higher the vertical and/or horizontal gradient, the closer together the verticals should be.**

This is explained by the fact that, when the data is examined, each vertical unit's profile is applied to an area on either side of it. The farther apart the vertical units are, the larger this "application zone" is. By reducing the space between verticals, we reduce the "application zone" and more accurately represent the actual variations of the stream bed and water speeds. We can thus better square significant lateral variations with unit flow data. The more regular the stream bed and discharge, the more regularly we can space the vertical units.



Point by point measuring

The number of points per vertical unit must take into account the depth, the vertical variations in water speed and the equipment used to take the measurements. It should, in any case, permit the most accurate representation possible of reality.

Here also, it is practically impossible to establish one universal rule. The points can be spread out evenly on a vertical axis, taking more measurements from the bottom half. The points should be spaced closer together if there is a strong vertical speed gradient, so as to best be reconciled with these variations.

In all possible measuring situations, it is better to avoid verticals with only one point of measure unless it is impossible to do otherwise, such as when measuring a marginal part of the total flow (at the edge of a zone where the water speed is extremely slow) or for safety reasons (surface speed measurements in flood conditions).

To correctly take into account the flow heterogeneity in time, the duration of a point measurement should be more than 30 s if the propeller speed is greater than 2 t/s ; the duration should be more than 40 s if the propeller speed is lower than 2 t/s.

As for the vertical units, it is advisable to place them as close as possible to the surface and bottom in order to minimize coefficients and surface effects.

Measurement by integration

Integration techniques depend on measuring the average speed at a vertical unit by moving a constant speed meter from surface to bottom (or vice versa). This allows the measurement to be done more quickly.

The ISO standard only deals with measurements of more than 2m in height. The integration speed must not be greater than 5 % of the water speed. The measurement must last more than 60 s.

Measurement integrating a wading rod and a small sized current meter is a French innovation. The results are comparable to point by point measurements. The speed of the raising should be adapted to that of the water and measurement time should be more than 30 s, even up to 45 s. This technique becomes viable when water depth is 15 cm or greater and is well adapted to vertical irregularities linked to the increasing proliferation of plants.

Comparison of the two methods

Point by point gauging enables a posteriori an evaluation of the measured velocity field. It is just as precise but richer in data than the integration method, which is nonetheless, faster to do.

Measurement by integration should be used:
- when the section is very deep
- for measurements from a boat
- when there is rapid variation in the depth
- when there is grass, after clearing the section

In stream gauging, it is difficult to apply a particular set of fixed rules. The number of vertical units, the number of points for each vertical or the speed of vertical integration all should be adapted to the characteristics of the section. The main concern is to represent reality as closely as possible. So in the case of a high gradient, there must be a greater number of measuring points.

Special advice

In the case of irregular and/or widely divergent variations, you should note the height of each vertical. In this case, the discharge calculation will have to be made using the independent vertical method. No matter what, the beginning level and the ending level of the gauging must be recorded.

When using a boat for gauging, the safety rules should be followed, not only when setting up the operation but also when taking the actual measurements. Safety vests are imperative during this activity. Measurements from a boat allow us to resolve problems and uncertainties associated with taking measurements from a bridge (the effects of pilings, upstream surveillance, etc.). This method of measurement requires more time and effort to prepare but the time needed for the measurement itself can be reduced considerably. The system for attaching the boat to the abscissa cable should include a quick release clip allowing the boat to be freed rapidly, if necessary.

Measurements in high water conditions are dangerous. During flooding, when we cannot do gauging, other data can be usefully collected: photos, the water line, surface water speed, observations about the flooding conditions (see checklist in annex). Flow measurements during flooding should be taken as quickly as possible in order to minimize the variation in water level (in case of rapid rise, for example) and to minimize the exposure of equipment and personnel to the risks of floating debris and other possible dangers.

When doing gauging in high water conditions from a bridge, the safety rules are equally important, especially concerning road signs and conditions of waterway congestion. Whenever possible, it is a good idea to use a single span bridge for this work.

This is not always possible, notably on large rivers which are usually crossed by multi-span bridges. It is advisable to make the water speed measurement as close as possible to the arches. To the extent possible the gauging should be done on the downstream side of the bridge with the measurement taken at a point vertically(directly) in front of a piling. When a measurement must be taken on the upstream side of the bridge you must take one measurement for each arch and, of course, add them to get the total flow.

In the case of strong flooding conditions, it is imperative that the measurements include all of the flow. So be sure that overflow runways or secondary branch , even far removed from the stream in question, are not functioning.

Likewise, within reasonable safety limits, measurements must be taken of lateral overflows. Most of the time it is more of an estimation than an actual measurement, depending on how far laterally the flooding goes. One way of estimating is to count steps laterally away from the streambed, then to calibrate the steps on dry to make the calculation. It is useful to take note of fixed reference points (poles, trees, etc.) compared to where the verticals are placed.

2.1.4 Calculations

At the measurement site, the field checklist (see the French version) should be filled out. On this checklist, in addition to information concerning location, date, time, people involved and conditions of the operation, all other information about equipment used as well as particular observations which could be useful in the calculations will be noted. Obviously, this includes numerical data for the calculations: abscissas, the depths of banks and verticals, correcting coefficients, propeller speed in number of spins and time of measurement or integration time, etc. This worksheet could be reused in 10, 20 or 30 years. Make the writing readable, the numbers clear and legible for future use.

This phase of recording on paper is obligatory, even if the examination of evidence is to be done right there in the field in real time. In any case, you should plan a printing at the same time as you record the data. You should get into the habit of this practice but that also means to reexamine and rethink about the materials currently used.

Different practices in making calculations could, for a given gauging operation, lead to significantly different results.

Concerning the data recording itself, it would seem very useful to use a visual graphics program for measuring verticals profiles (for point by point measurements), for discharge and for wetted sections. These representations should remind the measure taker of what he "saw and measured in the field" and therefore, to notice possible anomalies. This software program should be easy to install and use and be compatible with standard output devices such as colour laser printers.

Archiving flow measurement data is equally necessary. This should allow the accumulation of data and also be easy to use in order to access "historical" data in the event an error is discovered later on.

Archiving and storage is as valuable for field worksheets as it is for calculation worksheets. Saving hardcopy records is imperative and backing up computer file records is highly recommended. It would be wise to have computer storage of all raw data concerning a gauging operation, not just the rating curve data. Computer files on gauging operations should offer the possibility of multi-variable sorting which would allow data to be used in ways that the original measuring operation had not intended (for ex. drainage basin approach). The quality of data recording facilitates the eventual use of the data.

2.2 THE ELECTROMAGNETIC (EM) CURRENT METER

2.2.1 The principle

Inside the submerged sensor, an induction coil creates a magnetic field between two fixed electrodes; the movement of the water, the conducting fluid, within this magnetic field, produces voltage proportional to its speed. (Faraday's principle). This induced voltage is electronically processed by the measuring unit and converted into information that can be used by the operator.

The speed displayed on the counter represents an average, measured over a fixed time that is set by the operator- 1-120 seconds for the Flo Mate, 2-60 seconds for the Sensa Ott- but it can also be measured instantly (in hydrobiology applications, for example).

The current meter is theoretically 100% accurate since the current speed measured is perpendicular to its axis; however the angle of inclination to the water surface has been observed to have an effect on the measurement.

2.2.2 Setting up

The sensor is attached to a pole whose diameter depends on the type of meter used- 10 mm for the Flo Mate, 20 mm for the Sensa Ott- with or without data recorder. Assembly on a sounding weight is not currently possible.
For the Ott model, the manual says that it doesn't matter whether the sensor is placed above or below the electrodes: it will not change the measurement.; we have found that people prefer nevertheless to keep the electrodes above the sensor.

The measuring technique used is the point-by-point current meter method, choosing the number of verticals in the velocity field and the number of points per vertical.

The electromagnetic current meter is good for measuring water velocity in low speed currents or grassy conditions where micro-current meter type current meters are not very efficient.

The ranges of measure vary according to the model:

- for the Sensa, from .005 to 1.5 or 2.5 m/s depending on the setting. According to the manufacturer it is accurate to 1.5% of the measured speed.
- For the Flo Mate, from .15 to 6 m/s with a 2% margin of error. The stability at zero, is ± 1.5 cm/s

For negative speeds, the Sensa gives a signal and the Flo-Mate will actually measure them within certain limits. In the case of the former, values can be determined by simply turning the meter around to make the measurement which is accurate to a few cm/s.

2.2.3 Results of experience

The EM current meters are preferred to micro-current meter models used in point-by point measurements. Flow measurement results are comparable for a given measuring section . In a single point, the dispersion of observed results is slightly wider, though the reasons for this are not clear at this time.

Advantages

Measurements in slow water conditions are possible, under 5 cm/s, for example, but you shouldn't have illusions about accuracy in such conditions since the putting the measuring device in the water creates a thermal convection current of its own, on the order of a few mm/s.
Measuring in the presence of grassy growths poses no particular problems, a considerable advantage over the micro-current meter models but that does not eliminate the problem of representitivness of the points chosen. All the same, in heavy waters, the risk of deterioration is minimal.
The same sensor measures a larger, though limited, range of speeds. The absence of movable parts seems to be an advantage and he speed measurement read out is direct. But even if the EM current meter is a bit more resistant to shock than the micro-current meter type, it is not invulnerable to deterioration.
It provides the velocity value directly.

Disadvantages

In case of problems on the cable, reparations are difficult. The weight of the Ott meter, several kg, is a problem; the Flo-Mate weighs only 1.65 kg.
The electrodes must be frequently cleaned; preparation and reinitialization after a prolonged period of non-use are also constraining factors. Ott recommends recalibration every two years whereas the Flo-Mate has a procedure that sets it back to zero.
Drag is greater than with a micro-current meter model which causes some problems for correctly judging water depth in certain conditions such as shallow water or slow current, etc.

2.3 THE ACOUSTIC DOPPLER CURRENT PROFILER (ADCP)

2.3.1 The Principle

The Acoustic Doppler Current Profiler (ADCP) makes vertical profiles of water speed using acoustic energy. This borrows from oceanographical techniques in the field of hydrometry. The ADCP has four transducers that emit ultrasound signals independently of each other; these signals are transmitted in groups of pings.

The basic measuring theory is that the varying quantities of suspended sediment in water move at the same speed as the water itself. The ultrasound signals are transmitted, then reflected by the suspended sediment back to the ADCP with a frequency delay proportional to the speed of the water current.
The signal is used in two ways; the elapsed time of the rebound allows you to calculate the depth of the section measured and the change in frequency allows the calculation of average water speed in the section measured.

The ADCP measures:

- water current speed at various depths of a measuring vertical using the Doppler effect
- the geometry of a measured gauging section
- its own speed and direction of movement in relation to the stream bed again using Doppler in conjunction with a gyroscopic compass and a pendulum which determines verticality.

Crossing from one bank to the other, the ADCP integrates the various data collected and thus calculates the stream's discharge.

2.3.2 Set up

The ADCP is made up of:

- a submersible aluminium unit which contains 4 transducers, resistant to a depth of 1000 m, assembled using no magnetic materials,
- a compass
- a pendulum to correct for verticality
- a temperature sensor
- a surface control unit which, though an external power source, provides electricity for the submerged unit, allows the ADCP to be programmed and allows collected data to be downloaded to an external PC for storage and analysis.

The ADCP is most frequently set up and operated from a boat which crosses the stream to be measured; the recommended speed for crossing is less than 4 km/h, keeping in mind, the slower the speed, the greater the possibility for accuracy with an optimum speed of 2 km/h.

The ADCP measures its own speed relative to the stream bed with the aid of a gyroscope and a pendulum to correct for verticality and the water current discharge measurement is independent of the device's movement.

Given the rapidity of the examination of the velocity area, it is imperative that several crossings be made to establish a significant measurement sampling: the final accuracy of the gauging comes from the abundance of measurements. Moreover, the repeatability of the measured discharge constitutes a good indication of its quality.

The operators have on board with them a program which allows them to configure the operational modes of the ADCP, to acquire and examine the collected raw data (depth, average speed, etc.) and to test the correct operation of the measuring process.
The operator notes the salinity and temperature of the water; variations in these characteristics are automatically compensated by the ADCP sensor.

2.3.3 Limits

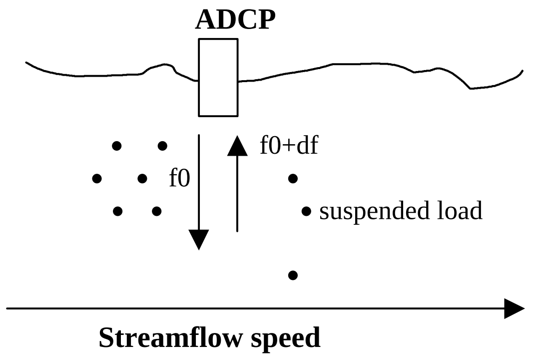
The driver of the boat should be concerned exclusively with the task of carefully handling his craft. Movements by the other members of crew should be reduced as much as possible to keep a horizontal position.

Do not allow bubbles near the transducers. Keep the boat speed low. If another craft passes, allow a waiting period before taking the next measurement.

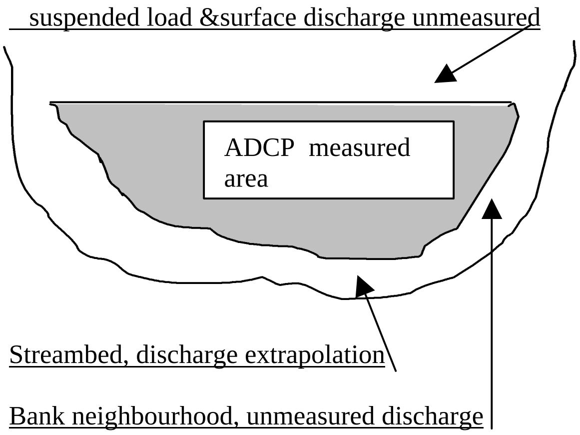
It is advised not to take a measurement in the downstream vicinity of a waterfall. Finally, in water with concentrations of suspended sediment greater than 1.5 g/l, the ADCP will not be able to detect the bottom and will give erroneous readings.

The transducers work both as transmitters and receivers; the ADCP switches back and forth from one function to the other. A certain distance is necessary to allow for the dampening of the transducer vibrations created by the transmission. The transmitted acoustic signal is made up of several distinct impulses with slight time lapses between them. Then the signal must be filtered, to reduce risk of confusion between the end of one impulse and the beginning of the next, which could yield incoherent data. All these processing steps eliminate any link between the measurement itself and the results of the calculations.

The main limitation in using the ADCP is that it doesn't measure all of the different water speeds from the surface to the bottom and from bank to bank. Indeed, the transducers must be kept continuously submerged at about 25 cm beneath the surface, which leaves the first layer of water unexamined. The bottom layer measurement is likewise limited by interference between emitted soundwaves and those rebounding off the bottom of the stream.



These unexamined layers are reconstituted by a software program; this mode of examination of "the extremities" (the top, along the banks and near the bottom) requires a comparative calibration gauging that establishes the parameters of the measured section.



This apparatus will only work properly in depths of greater than 1m. To obtain high quality measurements, it is preferable that the shape of the measured section be as close as possible to a rectangle with relatively steep banks at least 20 meters apart.

The range of water speed in which these measurements can be accurately made goes from several m/s (whatever does not jeopardise the safety of the crew) to as low as 10 cm/s. Less than 10 cm/s, the values will be displayed but their accuracy will have to validated.

2.3.4 Conclusion

The ADCP is not in competition with other equipment but expands the range of hydrometric techniques already available. It is a tool well adapted to large, slow moving rivers, relatively deep and wide. For these kinds of waterways, the current meter gauging could be too time consuming, too complicated in terms of river bank variation or navigation and sometimes virtually impossible to gauge because of their very slow water speeds.

Therefore, typical ADCP applications would be in downstream sections of large rivers such as the Soanne, seine, Garonne, Rhone, etc.

To our knowledge, there are currently five hydrometric organizations which have acquired ADCPs: the DIREN Rhone-Alpes and Ile-de-France, the CNR, EDF/DTG and ORSTOM (IRD). Each of them has done several gauging operations which have yielded the following observations:

- the choice of the stream section to be measured is the most important parameter affecting the final quality of measurement (not a new idea in hydrometry)
- compared to classic measurements using a current meter, we have been able to identify and record the underestimations of Doppler measured discharges. Investigations are underway to identify the causes: inaccurate extrapolations of velocity field fringe areas, or biases in the measurements.

Because the equipment is American, most of the documentation and manufacturer contacts are in English. The 1997 price of an ADCP was about 650 000 F (99 000 Euros), 150 000 F of which is for spare parts. A simplified version of this device was to have come on the market for about 160 000 F (24 300 Euros).

2.4 FLOAT GAUGING

This method is used only measuring surface speeds or, more exactly, speeds in the top stratum (about the first 20 cm) of the measured stream
.

2.4.1 The floats

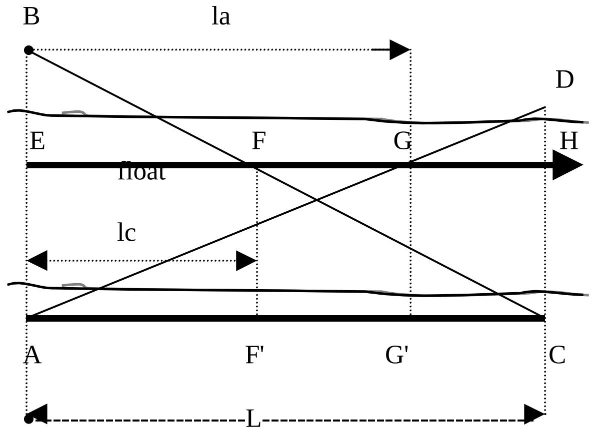
In the simplest of cases, the use of natural floats: tress, large branches or other floating masses heavy enough to be really representative of the flow speed. Extra care is required when spotting and identification of floats is done by upstream and downstream teams.

In the case where man made floats are needed, empty plastic 1.5 litter water bottles seem well adapted for the job. Don't forget to add a bit of ballast, sand or dirt, to the bottom of the bottle so it floats in an upright position with conical top out of the water (minimum surface exposed to wind). I t is also recommended to use Florescent spray paint on the bottles to make them easier to see.

2.4.2 Operating mode

When in flooding conditions, it is a good idea to identify and plan a float measuring run before a crisis situation arises. The length of this run should be long enough that the floats will need 30-50 seconds to travel from the beginning to the end. It should be located in a reach that is a straight run of water, far enough away from bends, bridges, etc., that the flow of water is not too disturbed.

The two chronometer (or clocks) method seems to be the most efficient for this measurement since it allows us to identify float positions and trajectories in relation to a bank. It entails the timing of floats by two teams (up and down stream). The floats are timed over the total course distance by both teams. In addition, each team times the floats between two intermediate markers placed diagonally (upstream and downstream) in mid-course (see diagram). It is these intermediate times that allow us to calculate the position of the floats.



The speed will be equal in relation to the length of the measuring run by the average of the two total times recorded by the two teams.

We suppose that the markers AB and CD are perpendicular to the flow of the stream and that AC is parallel. If this is not the case- if AB and CD form an angle x to the perpendicular of the flow direction, then we have to correct the calculated positions of the floats by cos x.

The calculation of float position is the simple application of Thales theorem on the two triangles ADC and ABC.

In the triangle ADC:
tA = time to cover total distance la. Ta= time to cover distance L

$$\frac{GG'}{DC} = \frac{AG'}{AC} = \frac{la}{L} = \frac{Va * ta}{Va * Ta} \Rightarrow GG' = xa = CD * \frac{tA}{Ta}$$

In the triangle ABC;
tc = time to cover total distance l-lc. Tc= time to cover distance L

$$\frac{FF'}{AB} = \frac{F'C}{AC} = \frac{L - lc}{L} = \frac{Vc(Tc - tc)}{Vc * Tc} \Rightarrow FF' = xc = AB * \frac{Tc - tc}{Tc}$$

By repeating this operation at different positions along AB, we can determine "virtual" verticals and calculate the floats on each one. In fact, we have the examined velocity area of the surface.

The average flow speed thus obtained will be multiplied by the average value of the wetted section, obtained by the minimum transversal profiles of AB and CD.

Conclusion

The float measurement method should only be used when it is impossible to use classic current meter methods. This method, used wisely, and in a conscientious manner will result in a very discharge estimation. This means that the teams must be well trained and thoroughly prepared with respect to the field conditions and the equipment.

2.5 DILUTION GAUGING

(often called chemical gauging)

As a reminder, let us point out the fact that there are two methods of dilution gauging: the instantaneous injection method and the constant injection method.

The principle of these two methods is the injection of a tracer solution of a given concentration at a specific point along a stream of water. Then the concentration of the solution is monitored downstream along a distance far enough to ensure that it is sufficiently mixed with the water. The discharge is then deduced by comparing the concentrations of the injected solution with the water sample taken downstream.

There is no conflict between this method and use of classic current meter methods. To the contrary, they are complementary. Dilution gauging is interesting when the measuring section is varies greatly over short distances, when current is quite turbulent or when the use of classic techniques poses a safety risk to personnel.

Therefore, when velocity area methods are not appropriate, dilution gauging methods may be employed.

It is not a question of planning to use one method or another but to use the dilution method to expand the limits of the other.

This method requires special training of personnel, in the field as well as in the lab. The time needed to make the measurements in the field is the same overall since the time needed to collect data is rather constrained (physico-chemical dosage, etc.)

This method also requires the acquisition of laboratory equipment (for fluorimetry), tracer chemicals (rhodamine WT, sulferodamine G, pyranine, Eosine, etc.) and the use of equipment that has been adapted for injection (most often custom made by the team itself. Specific training should be given to personnel before this method is employed and should then be maintained with regular use or training sessions.

CONCLUSIONS

As far gauging goes, there are no fixed, unchangeable rules. The main objective is to get as close as possible to the existing realities of the field.

The choice of measuring methods and the means of implementing them is a function of the configuration of site, available resources, both human and material, and the degree of accuracy expected.

In difficult conditions, such as equipment breakdowns or dangerous situations, estimations of speed, photographs taken, observing floodwater marks on permanent structures, etc., are actions that can mitigate the absence of a true measurement and establish coherent limits on further evaluation of a site.

The selection and adaptation of gauging sites, competence of personnel, equipment to be used for a job should all serve to advance a project toward optimum measurement precision.

The most important elements for good measurements are motivated, well trained and properly equipped personnel. Not only the must the measuring equipment itself be in good condition, but also the annex equipment must be in good working order. In other words, for good measurements, you also need good vehicles.

Harmonization of practices comes with the profound motivation of men, with skilful development of collected data and a grasp of the basic notions of hydraulics.

CHOICE AND INSTRUMENTATION OF STATION SITES

Some definitions would be useful to avoid any confusion in the nature of measuring sites:

- water level station: a site where water levels are observed
- water level recording station (limnigraph): site where water levels are continuously recorded
- gauging station: site where water discharges can be calculated
- gauging point or section: site where instantaneous discharge measurements can be made.

1 TRADITIONAL HYDROMETRY

A traditional station is defined as a site where discharges are determined from a group of instruments based on what is considered a univocal relationship between water level and discharge.
Thus the station is made up of:

- a site with several control sections
- a staff gauge
- an array of sensors, recording instruments and/or transmitters
- an equipment chest and possibly a small building for maintenance and storage.

The European norm 1100, part 1, deals with station characteristics.

1.1 BASIC PRINCIPLES FOR CHOOSING A SITE

The relationship between the water level of a stream and discharge is defined by gauging measurements. Before choosing the location of a gauging station, it is indispensable to examine the site's potential for effecting discharge measurements.
In all cases, the first close check of the topography should be made using a 1/25000 scale map; then several trips the site under different conditions (low, medium and high flow) will confirm the site's suitability. Lastly, before the final decision is taken, visits should be made to local residents, local authorities and other organizations that have worked in the area and have historical knowledge about water conditions there, particularly, the highest water levels.

The choice of a site is a compromise between technical constraints and the objectives of the station. In some cases, there might not be a way to get a discharge measurement using traditional means or, it might be necessary to make significant changes to the location chosen.

1.1.1 Administrative procedures for the creation of a site

The location of a measuring station is neither included in nor protected by any administrative procedure. Our advice is to ask the local authorities, explaining clearly the purpose of the station and providing photographic documentation about the type of installation planned.
However, authorization by the property owner is indispensable. Concerning public property, the department responsible for the land in question is usually responsive to the value of our work. On private property, public records will yield the name and address of the property owner. The durability of the installation depends therefore on the property owner's interest in the work we do.
All the corresponding elements will be kept in the station's file.

1.2 CRITERIA OF CHOICE

The ideal site rarely exists in nature; the site chosen must nevertheless meet, to the extent possible, certain hydrological criteria.

1.2.1 Fidelity

All discharge to be measured must run through the section. If this is not possible, we must be able to account for whatever is causing the problem (back water works, overflow of embankment, etc.)
Zones which contain aquatic vegetation are to be avoided.
The relationship between water level and discharge, verified by frequent gauging, should be as much as is possible, univocal, that is, each level should correspond to one and one only discharge.

Long term ground stability of gauging sections is one of the most important criteria sought and may possibly require construction of a sill.
En theory, the flow in front of the station should be:

- uniform (as measured in a canal of a straight section
- permanent

A current is considered permanent when its hydraulic characteristics remain constant in a given section as a function of time. It is considered uniform if, in addition, the velocity vector constant along every streamline.
As a practical matter, rivers don't always meet these conditions.
That makes it necessary to find a control section with a constant shape and where the approaching

current speed is slow, followed by sufficient acceleration so that all changes in the flow downstream will not have any effect on the upstream bank of the control section.
An upstream control can be:

Natural

- by lateral narrowing of the channel
- by a natural sill

Artificial

- by a man made sill, adapted to have an effect in low flow and little or no effect in high flow

A naturally occurring narrowing is a preferable location: the up stream risks are minimal and it is sure to be permanent.
It is often difficult to find a site with a single control section. A rating curve is then constructed by integrating the changes of the control. When the natural conditions are such that a natural control cannot be found, the solution is to build a sill. (artificial control).

1.2.2 Sensitivity

So that the control station can detect small changes in discharges, slight variations in flow must result in changes on the gauge that are large enough to be read. The "basic unit" can be considered as the flow variation that corresponds to a movement of 1 cm on the scale, a change that can be easily seen.
The sensitivity of a station is further enhanced when the roughness is important, when the slope is gradual, the depth is big enough and cross section is not wide.
The sensitivity can be quantified using a rating curve . The study of variations in discharge show significant differences among low, medium and high flow conditions and, depending on the morphology of the stream bed.
To evaluate the sensitivity of a potential site, making a sketch of the rating curve permits you to anticipate certain other problems; installing a staff gauge and doing a few discharge gaugings will help to identify the constraints of the site.
A quantification trial on a few selected stations in the Seine and Maine basins resulted in quantifying the sensitivity of one station by breaking out the changes in discharge values that corresponded to a 1cm change in water level for a battery of hydrological parameters. The discharge characteristics used were:

- low flow water- statistic parameters for a five years return period : VCN3 (minimum volume on 3 successively days) and QMNA (multiannual minimum discharge)
- in medium water- the module and daily flows at 95%
- in high flow- 2 year and 10 year flow peaks

The average sensitivity by category is the geometric mean of the sensitivities found for each of the two characteristic discharges of the category.
The proposed limits are provided by "expert" experience and ought to be validated by a more methodological approach.

Site rating	not very sensitive		sensitive		very sensitive
Low flow		40%		20%	
Medium Flow	$\frac{\Delta Q}{Q}$	**> 10% >**	$\frac{\Delta Q}{Q}$	**> 5% >**	$\frac{\Delta Q}{Q}$
High flow		4%		2%	

A good sensitivity in low flow conditions translates into noticeable changes in water level when there are slight changes in discharge, which is not easy to obtain. Also note that sensitivity falls with the first overflowing in flood conditions.

1.2.3 Accessibility

The station should be accessible in all circumstances especially during flooding. A few simple site improvements can sometimes make conditions more practical (especially access roads to the station as well as the gauging sites).
The distance between where you park and the station itself, safety conditions at the station and at the measuring sites and road accessibility are factors which have a considerable effect the daily management of such an operation.
An ideal site with difficult or dangerous access is not as good a choice as a site that, although a little less satisfactory in hydrological terms, will be used on a continuing basis.

1.2.4 Technical constraints of a site

The station should be designed to remain operational even in extreme flooding. An inquiry about the highest known water conditions will allow you to locate the equipment out of flooding range.
The staff gauge should be located as close as possible to the sensor (e.g. in the case of wells, the oil sump filter acts as the sensor) and installed so that it is easy to read at all levels, is readily accessible for maintenance and will not be disrupted by floating debris. **The zero level of the staff gauge should be hooked up to the NGF system and to one or more well identified local markers**.
The sensor should be located so as to avoid possible backwash and buffeting; A sunny spot is often favorable for the growth aquatic vegetation.
Stagnant water zones often lead to problems of silting up and create a need for added maintenance

and sometimes preclude the use of certain techniques. Electric and telephone services are a definite asset. It is a good idea to ensure protection against electromagnetic interference. A study and on-site test measurements are recommended before the installation of equipment for a modern station, (for example, which automatically transmits its data). Finally, there could be technical constraints specifically associated with each sensor that would lead to the choice of equipment based on the site as well as special civil engineering work adapted to the site.

2 DOUBLE STAFF-GAUGE STATIONS

2.1 BRIEF REMINDERS

It is sometimes impossible to find a stream section where water level and discharge are directly linked, notably when the staff gauge is located in the backwash of a mobile dam. The same reading on the gauge could be associated with different discharges.
Calculation methods used for determining the discharge are derived from Strickler’s formula:
$V = K \times Rh^{2/3} \times I^{1/2}$
Where **V** is the speed in m/s, **K** is Strickler’s coefficient, **Rh** hydraulic radius in m and **I** is the slope.
The discharge is determined by measuring water level at two points which allows us to define the slope. Once the cross section is recorded, the hydraulic radius is subtracted from the level measurement; Boyer’s method is basic method used in HYDRO. Other formulas derived from this method are used by some station managers.

2.2 INSTALLATION

2.2.1 Choice and location

The 2 stations should far enough apart to allow a satisfactory measurement of the difference in water level between the two gauges. This means the choice of a sufficiently long reach in the case where there is slight slope. The stations should be located a few hundred meters from either end of the reach.
The flow in the reach should not be subject to major disturbances. For this it must have regular geometric proportions all along its length. To be altogether avoided are sections with pools which fill and empty in an irregular fashion or tributaries which flow into the reach. Also avoid areas where dominant winds blow along the same axis as that of the reach.
The upstream station usually has the reference gauge and also serves as the current meter gauging section. This means easy access to this measuring section, flow regularity in the immediate vicinity of the station itself, a regular crosscut profile and straight, clean banks.

2.2.2 Set up for measuring slope

Staff gauges
The upstream and downstream stations should have a staff gauge that is clearly readable and protected from the wind (the effects of buffeting)

Sensors

The correct installation of sensors depends on the precision of information, therefore the calculation of the difference in water level between two points of measure.
No matter what, the sensors should inside or under vertical stilling wells connected to the stream and in close proximity to the staff gauges and high enough to be protected from high flow. The wells must have a minimum diameter of 1m.
Regardless of the style of sensor, it must be accurate to 0.5 cm. It is advisable to monitor the synchronization of clocks and proper simultaneous operation of mechanisms.

2.2.3 Operating precautions

A twin gauge station is generally set up on a river with a slight slope. Staff gauge readings demand close attention and should be taken carefully, avoiding parallax errors.
If you use a paper limnigraph, (1:5 scale), here are a few precautions:
- insert the paper sheet with care. Also use high quality paper to avoid distortion due to humidity
- make sure that the recording pen is properly positioned

To permit the correct setting of the sensors, each station should be equipped with a sounding support overhanging the wells; its altitude will be determined relative to the N.G.F. Thanks to this system, the level of the water in the stilling well can be measured to the millimeter and the slope can be very precisely calculated. To facilitate this operation it is a good idea to cut off the flow from the river to the well using a valve on the water diversion tube.
For the gauge setting operation, be careful that the flow in the reach is not disturbed at the moment of the measurement. Particularly in low flow conditions, in the case of a navigable river, it is essential to take these measurements during non-navigation hours to avoid the undesired effects of boat wakes.

These same recommendations are valuable for flow measurements to check the current meter characteristics. They should be done during non-navigation hours and when the water surface is calm (generally very early morning).

2.3 METHOD LIMITATIONS

The precision of discharge measurements depends essentially on the precision of the water level readings and setting the sensors.
However, the lower the difference in levels between gauges, i.e., in periods of weak flow, the less precision you will have. In other words, the uncertainty of the value given becomes more uncertain.

Example: Breillorse
(B.V. 5700km^2)

Module 27.9 m3/s	Average accuracy 4%
2 yearly low 19.6 m3/s	Average accuracy 8%
10 yearly low 13.3 m3/s	Average accuracy 16%
Minimum Q 7 m3/s	for ΔH= 0.02 m

The multiple variations affecting a body of water do not allow the determination of instantaneous discharges; the default time scale is one day.
In a period of low flow, recording the wind speed gives an added dimension to the quality of the data.

2.4 THE PROBLEM OF FLOODING

The method of calculation comes from Strickler's Formula, assuming that the coefficient K is constant. If the river is not dammed in its low-flow channel, the flooding field will make the value of K change. Therefore, stream gaugings are still imperative.

CONCLUSION

Technical evolution is moving towards the disappearance of twin gauge stations, increasingly replaced by ultrasound velocity measuring stations, the main obstacle to this change being economic. This evolution will also provide more accurate discharge measurements in low flow conditions.

3 ULTRASOUND MEASURING STATIONS

Stations which directly measure stream current speed by ultrasound waves were developed and put into service in Switzerland in the early 70's. They were then used in other European countries (UK, Germany, the Netherlands). It wasn't until the late 70's that the first such stations were installed in France: Paris Alexander III on the Seine and the "Canal du Nord". Currently, some 15 stations are operating on French rivers: CNR, DIREN Ile de France, Nord pas de Calais, EDF DTG, SN Strasbourg and Lormines. Stations of this type are widespread in the area of water treatment (see DDE 93, GEMCEA)

The main manufacturers are: Stork (the Netherlands), Atlas Krupp and Ott (Germany), Ultraflux and CR2M (France), Peak-Martac (USA), AFFREA-Hydrosonic (Canada).

This kind of measurement is interesting because it permits us to calculate the discharge even if the water level-discharge relationship is not unique (afflux due to an impoundment or a reach subject to tides). Ultrasonic measurements provide the parameters needed to calculate discharge, i.e., the water level and the average current speed at the depth of the measuring cord. And, the values displayed by the ultrasound sensors being algebraic, this system can also determine the direction of the flow.

The major interest of this type of station is, therefore, the ability to measure discharge where classic gauging methods cannot. But contrary to a widely held idea, this mode of measurement still needs to be validated in very low speed water conditions. Indeed, this type of station provides only average current speeds over one or several horizontal lines of measure. Traditional gaugings are still necessary to establish a relationship yielding discharge as a function of the water level and the speeds measured, so it is imperative that it be technically feasible to perform gauagings over the whole range calibrations.

3.1 THE PRINCIPLE

Measuring water speed by ultrasound is based on measuring the time it takes impulses to travel back and forth between paired transducers and water in movement. The difference between impulse sent and impulse received can indicate the direction and the speed of the current. The line connecting the two transducers is inclined at about 45° form the presumed direction of the flow.

The sensors can be configured to handle current flows that are not parallel to the riverbanks.

3.2 INSTALLATION CONDITIONS

You must find a site that is easily accessible to reduce the heavy cost of landscaping and facilitate station maintenance. It is also a good idea to choose a section where the streambed is stable in order to avoid frequent corrections of the parameters used to calculate discharges.

In the case of a single measuring line system, be sure to choose a site which does not have bends or direction changes, otherwise the measurements of average speed will be false.

The presence of obstacles in the current can affect the sound waves emitted and thus alter the measurement. Besides the ensuring regularity of this section, you must pay attention to aquatic vegetation in the waterway and watch for large amounts of floating debris. In addition, don't forget to take into account the effects of river navigation; when there is a lot of traffic, dispersing air bubbles can greatly perturb the measurement.

Ultrasonic measurements are inadequate for rivers where the concentration of suspended solids is greater than 1.5 g/l during some flood conditions because there is too much signal attenuation.

3.3 RESULTS OF EXPERIENCE

Five years of experience operating EDF DTG ultrasound velocity measuring stations have yielded the following principles of installation:

- this measuring technique is interesting when classic gauging techniques cannot get the job done but its cost (around 23 000 Euros not including site improvements) is a limiting factor in its being commonly used
- installation must be done with great care, paying rigorous attention to details such as angles and cord lengths; it also presupposes special operator know-how which can only be acquired by experience with this type of station
- maintenance and replacement of transducers should be able to be done easily
- a minimum of 5 -10 traditional gaugings must be made to establish the initial discharge calculation parameters. This hydraulics calibration will be different depending on the type of watercourse:
  - if the current is regulated both up and downstream, with only a slight tidal range, the determination of a calibration coefficient is made as a function of average current speed
  - if the current is not regulated, calibration is determined as a function of water level
- the average current speed is calculated using 10 or so raw measurements in order to eliminate the effects of temperature variations, especially sensitive in low speed conditions. A validation is necessary in order to detect the aberrant values and to store 10 validated data sets .

4 DOPPLER MEASURING STATIONS

4.1 THE PRINCIPLE

The Starflow functions as an emitter and at the same time as a receiver of ultrasound frequencies. The current speed is measured thanks to fine particles suspended in the water and which act like moving mirrors. The sound wave undergoes a variation in frequency because of the movement of the reflecting particles. This variation in frequency allows the speed and direction of the current to be calculated. Likewise, reflections of sound waves on the surface of the water allow the computation of water level.

Knowing the cross cut profile of the section, it is then possible to calculate the wetted section and, multiplying it by average speed, figure out the discharge.

The only station currently using this type of set up is DIREN Basse Normandy.

4.2 INSTALLATION CONDITIONS

Place the central acquisition unit on the bottom of the stream in a regular section and, if possible, in an artery with regular flow characteristics. It is best to attach it to a mobile platform which is lowered into the river along a line attached to a stake planted at least 1/3 of the way across the width of the section, though this could get in the way of river traffic. The central unit is entirely submerged; only the battery and the modem remain out of water on the bank. Any adjustments to the Starflow require it to be brought out of the water. The variable length power cable and RS 232 cable which link the central unit to the battery and modem are fixed to a chain that is laid on the bottom. Installation and maintenance are rather complex and time consuming operations but this device yields reliable and coherent results. Current speed and discharge data, should be initially validated , of course, by gauging.

4.3 RESULTS OF EXPERIENCE

This type of equipment allows discharge, water level, direction of current in estuary zones to be measured with good sensitivity. It opens up, therefore, interesting possibilities to resolve some situations which current can not be addressed with other traditional techniques.

The equipment tested in 1995 at DIREN Basse Normandy has been totally satisfactory. The two stations purchased in 1996 had some communication problems, notably for retrieving data files. These kinds of problems can probably be fixed quickly because it has to do more with software than hardware.

5 SITE TOPOGRAPHY

A detailed topographical survey of a prospective site is highly recommended. This should be comprised of three crosscut profiles: upstream from, directly at and downstream from the measuring section. If necessary, it should be completed by a stream profile. These surveys will allow you to determine the slope of streambed, the cross section, control and hydraulic characteristics, overflow points of each bank, etc.

This survey information should be organized and added to the site file. Its use in determining the rating curve is essential. In extrapolations, the absence of topographical information can lead to serious errors.

Likewise, photographs of the station site and the measuring section in different water conditions will allow you to envision the various flow circumstances possible.

6 THE STATION FILE

Hydrometry depends on written information in as much detail as possible, so as to mitigate our imperfect memory (the 5th gauging of the day could be confused with the 4th when we are assembling data two days later) or changes by the recorder or other persons involved in the process.

Coming back to old data is also one of the characteristics of hydrometry. In this case it is necessary to have data that is as complete as possible on the measurements concerned, to ensure reliable interpretations resulting in quality discharge information.
In this sense, we in hydrometry have long been exercising quality assurance measures.

The same practices apply to hydrometric stations. The totality of data gathered is combined into a "station file" which is more and more complete to the extent that each staff member contributes additional information.
This file should include:

- a 1/25 000 scale map of the area, with a detailed sketch or a topographical record of the location.

- Administrative information: basin, department, commune, official registration, Lambert coordinates, zero altitude scale
- Authorization of the property owner for the placement of the station
- Photographic history of each step of site evolution (land improvements, equipment changes, etc.)
- An equipment registration system that includes a general summary of materials and management/maintenance records.
- Gauging records which lists the main discharge measuring sites, range of discharges measured, possibly a photo and notes on their accessibility.
- Historical follow up which mentions the main changes to the site over time (date, nature of change) and notes the observations made on the individual gauging record sheets.

The updating of this file is often considered a tiresome chore by station personnel. It is invariably of great usefulness whenever old anomalies are found which require data to be reanalyzed. For the hydrologist, the difference between trying to conduct a historical study with uncertain data and in which the witnesses have often disappeared, and having at hand the necessary data, clearly annotated, is considerable.

RECONSTITUTING HYDROMETTRIC DATA

1 SOME PRINCIPLES FOR THIS (SOMETIMES) DELICATE OPERATION

When the recorded water level measurements at a station are doubtful or haven't been made in a long while, the station personnel should take actions to fill this information gap, created in the continuous chronicle of water levels as a function of time (S/T).

The action necessary to rectify this absence of information is called "reconstitution".

The methods and difficulties involved in reconstitution are quite varied, depending on the amount of time for which data is missing. It is possible, nevertheless, to give a general idea.

1.1 THE EASIEST CASES

The easiest cases are usually on rivers with no external influences, concern relatively short periods (at most, 3 - 8 days), and occur during a time without rain or flood conditions.

In this kind of a case, it is often sufficient to retrace the water level variation curve as a function of time, starting from existing data, then transform the estimated water levels into discharges. This kind of situation should be considered an exception; reconstitutions should generally have to do only with discharges. The existence of a "doubtful water levels" code in HYDRO facilitates the transparency of this kind of reconstitution.
Careful! With the increasing incidence of "water uses" (irrigation, various draw-off, etc.), reconstitutions in low water conditions have become more delicate.

1.2 THE MOST DIFFICULT CASES

Reconstitutions are the most difficult when there is influence, especially contributions linked to rainfall. Here, the means needed for reconstitution are more consequential. Likewise, a long period with no information, several weeks, for example, requires a deft touch. If it has rained significantly, the reconstitution is all the more complex when the stream current reacts to the precipitation and is not as regularly fed by groundwater systems.

2 HOW TO RECONSTITUTE

The first rule in this type of case is to find, other than discharges of close-by measuring stations, available information on the rain that has fallen (the levels observed in the proximity, etc) that serve as elements for the basis of reconstitution.

It is essential to keep a record of the elements and methods used for reconstitution of missing information, even if the means used aren't perfectly orthodox.

With certain paper recording instruments, when the paper advances momentarily at a speed far less than normal, it is possible, using the "compressed" graph to reconstruct a plausible graph line, paying close attention to the peaks and gradients corresponding to rising and falling water levels.

In the case of a clock breakdown or forgetting to reset the stage recorder (other limnigraphs are also concerned), knowledge of the extreme values previously recorded is obviously invaluable since that gives you a range of water level variation during the breakdown, under the condition that the stylus remained in its normal position.

If there are no indications about the range of water levels attained during the absence of information (failure of electronic recorder e.g.) the rule becomes to use data from one or more comparable measuring stations, taking into account the amount of rain that has fallen in the basin concerned. The data teletransmission becomes interesting - it could supply measured data at regular step as well as the information concerning the equipment operating.

The following are considered comparable in terms of hydrometric stations:

- stations which are not very far apart, with a similar rainfall history
- stations whose hydrological regimes are similar (snow regime, permeable or non permeable drainage basin etc.)
- stations whose drainage basins are of a similar size and have similar response times to equivalent rainfall

If the time period of missing information is not too irregular or too long, it is then possible to envisage a reconstitution based on a correlation between discharges taken from the station in question and those of a "reference" station or stations.
Note: *It is usual to see the comment, "discharges reconstituted by graphic correlation" on daily discharge tables. This type of reconstitution is probably satisfactory for cases such as those described previously in the "easy" category. Still, it would be preferable to use regression analysis to correlate the existing streamflow parameters related to the station in question and the reference station, if the reconstitution covers a significant amount of time.*

3 HOW TO CORRELATE DATA

The variable to study can be:

- the average daily discharge
- the n day mean of daily averages
  where n = 5, 10, 30

It is preferable to use variables belonging to the same hydrological year and during the year of reconstitution. The use of variables from other years can be used to complete the approach. Beware of the existence of differences in discharges of "similar" rivers that could be the result of different climatological histories (depending on the year) of the respective basins.
For a correlation to significant, the range of discharges considered must be sufficiently distributed and framed within the range of those found at the reference station during the period concerned. The possible seasonality of the correlation will also be verified.

The formula obtained must make physical sense:

If: Q unknown = a Q known + b

a must be coherent with the comparison to drainage basins

b must be low compared to the range of discharges to reconstitute. Here again the geology could influence the principle. A basin flowing into permeable formations added to a basin flowing into impermeable formations could justify a large value for **b.**

When the area of respective drainage basins is too different, it often becomes necessary to use a logarithmic correlation of discharges.

A correlation formula that does not make sense must be rejected even if the coefficient of correlation is very high. Beware of samples that are too limited or too asymmetric which could lead to incomplete conclusions.

Visualisation of the points distribution of correlation is indispensable. For low and medium discharges the 'zoom' tool is to be used.

It is advisable to examine the evolution of the representative points of correlation before and after the period of reconstitution. The significant differences between points, if they exist, could be due to variations in rainfall in the two basins or a difference in reactions to the rainfall in the basins that the formula doesn't reflect. In any case, the application should be used with care.

A visual examination of the reconstituted hydrograph will be done. If necessary, it can be manually optimised to comply certain time delays and to maintain coherence in terms of the total volume of the streamflow.

3.1 PEAK DISCHARGES

If it is not possible to reconstitute them, it could be interesting to try to evaluate peak discharges of floods during the period of missing information in order to have a continuous annual series of maximum discharges (for calendar year or hydrological year). This becomes more delicate as drainage basins become smaller.

First you should look in the field if there are high water marks on permanent objects. You must be careful about marks left on trees or branches whose position might have been changed by the speed of the current.

In the absence of any such marks, there could be a possible correlation between known peak discharges at the "reference" station and those of the station in question; be sure not to forget to examine rainfall figures for the two drainage basins also.

When these stations are not located on the same river, or if their respective drainage basins differ greatly in surface area even if on the same river, there is a good chance that there will be a very loose correlation or that the estimation of the desired peak discharge will be in quite a broad range. Estimations derived this way can still be of value in situating unrecorded high water discharges in a sample of maximum flood conditions (annual maximums or flood levels above a certain threshold).

3.2 RAINFALL - RUNOFF MODELS

In certain cases, especially concerning extended basins for which there are hydrological models, we could see the use of rainfall - discharge relationships to do reconstitutions (the less permeable the basin, the easier this would be). Or, you could correlate discharge data between the station with missing data and other upstream stations, taking into account, if necessary, the propagation effects between stations.
The use of daily hydrological models (Cemagref GR4, EDF's MORDOR, for example) allows reconstitutions from rainfall. The difficulty comes in setting up the model, which requires considerable time as well as the integration of rainfall data itself.

If the absence of information is long and includes a particularly rainy time, you can assume it is not possible to make a very detailed reconstitution. Only the monthly discharge figures will be estimated. In this case, if seasonal variation is observed in the correlation, then analysis of correlations will be limited to the monthly discharge for one period of the year instead for the entire year.

An example:
In Œuf, in the upper parts of the Essone near Bondaroy is a groundwater outlet from an aquifer with considerable inertia. The discharge from this station was considered to be the sum of base flow (relatively stable over time) plus runoff from rainfall in the Pithiviers area.

The reconstitution is therefore done by extending the base flow recession curve and, when necessary, adding in the rainfall data calculated according to the actual rainfall.

3.3 ADVICE TO THE USER

One imperative rule concerning reconstitution is to express your values in only two significant digits, generally speaking (4.7 instead of 4.68). You can make an exception when dealing with discharge values between 1 - 2 m/s; in that case the last digit should be 0 or 5 (1,3 instead of 1.32 or 1.95 instead of 1.94).

A reconstituted water level or discharge should always be identified as such by using a validity code of 8 in the HYDRO databank. If the reconstitution is uncertain, don't hesitate to label it with a code 5, "doubtful".

CRITICAL PROCESSING AND VALIDATION OF DATA

The chain of data acquisition that includes a sensor, a code converter and a recorder is not totally safe from errors in interpretation. This system generates information that must be analysed, critiqued and corrected. These different steps don't occur in chronological order but must be repeated as necessary throughout the process, from the site survey up until entering the data into the hydrological databank.

The ultimate result, the discharge value, is, in turn subjected to a validation process. The necessary rigor of each step allows you not only to select most significant data but also to guarantee the integrity of the final result.

1 PROCESSING THE DATA

Setting parameters for the acquisition chain in terms of sample frequency, precision and intervals between memory updates is something that must be adapted to each river. It is useful to take measurements at different times according to water levels, as a function of each site's own characteristics.

The file of accumulated data contains a considerable amount of information for calculating the discharge, which makes it necessary for the subsequent detailed processing of that data.

The first check is on the terrain. The congruity between times and water levels for both the measurement sites and the water level recorder are compared. If necessary, essential adjustments are made. Then, verification of the parameters is done. A check of the linmigraph on record is made to detect any possible anomalies. If there are any, they are noted on the station log with a detailed account of actions taken to resolve the problem (battery changed, reset a recorder or gauge, etc.). This log contains the date, time, staff gauge level, all essential parameters as well as any notable changes to the station in a hydraulic context. Then, in the office, you will proceed with the normal processing of data.

Whether you use the graphic recording or digital recording, it is imperative to save the raw data, without any time limit, on a reliable medium. CD-ROM recorders now provide excellent low cost long-term storage solutions.

1.1 RECORDING PAPER

After identifying any recording anomalies that have been identified, whether caused by a discreet event or progressive equipment malfunction, corrections must be made. The basic verification is done by lining up the limnigraphs' beginning and end water levels and comparing the recorded values in between.

The "cherrying" is an intermediate limnograph processing step. The cherrying unit of measure is the mm. The curve is coded in a way so that the recording between two "cherries" can be reasonably assimilated into a straight line. The distance between a straight line defined by two successive cherry points on the curve and the actual curve should never be more than 5 mm nor should it generate a discharge error margin greater than 5%. In the case of significant variation in water levels, increase the number of cherries.

Graphic reversals on water level graphs should be analysed with precision and correctly entered/identified. The beginning and end water level values are indispensable. If there are multiple graphic reversals, the limnograph should be digitalised and carefully examined, which should allow you to find the error since the recording characteristics of raising water levels and falling water levels are different.

It is a good idea to monitor the continuity from one recording sheet to the next to avoid "stair stepping" of data limits.

If this step seems to simplify the curve, it is advisable nevertheless to pay close attention to even slight variations, which must be taken into account.

1.2 ELECTRONIC RECORDING

With the reduction in cost of data storage, it is much easier today to keep even moderate variations in amplitude. Good knowledge of the site is essential to judicious processing of the data. The following different steps can be differentiated in the processing.

Filtering consists of eliminating background noise linked to the accuracy of the measurement of the waterway as it is effected by surface turbulence, or slight, random, insignificant variations of a few seconds. The important thing is that the department is aware of the technical rules used by each site and that they are written and applied in a consistent manner. The amplitude of background noise is modest (up to a few mm).

Next you proceed to the smoothing out of the slight variations in water level which account for only a modest volume, which are more or less in equilibrium and which don't last more than 30 min on average. The source frequency is thus longer and the physical cause can be identified (example: a 'constant' levelling valve). Smoothing should be the result of a careful thought.

Examining the limnograph can reveal isolated or random values that should be eliminated. You should also think about reconstituting certain values in order to have a continuity of discharge (short time gaps in data or delay in water level, etc.).

Compacting is another step that involves breaking up the curve into discreet straight-line segments. This makes a far greater number of pivot points than if the process is done manually. This is the equivalent of the 'cherrying' process. The distance between lines defined by two successive cherries and the actual curve should not be greater than 5 mm nor should it generate a discharge error of more than 5%.

The visual inspection of the digital recording paper is extremely useful, as are the raw hydrograph record and the processed data which could validate or invalidate some simplifications.

All of today's information technology processes should facilitate the operator's job and should complement his expertise but should not take the place of physical examination of evidence.

Some software programs propose a smoothing function, automatically transforming raw data into average values by using a filtering algorithm for a wide range of discharge values. The absence of evaluation and control leads to masking significant information such as the beginning of a flood or the length of a maximum value. We advise you not to use this type of procedure.

Whether for graphic or digital files, you should always verify that you are working on the right station; it's always possible to switch data sheets by mistake.

Raw water level is what we call the limnograph recorded at the site.

Validated water level is what we call the processed results described above.

2 THE EVALUATION OF DATA

2.1 VERIFICATION OF COHERENCE

All during the processing, evaluation has played a part in correcting recording anomalies in the field acquisition chain.

A certain number of verisimilitude checks are should be done to detect divergent values by identifying outliers. Thus, a value of 10 m will be abnormal when the range of fluctuation is between 0 -4 m.

Comparing a gauge reading and the corresponding limnigraph will allow you to identify anomalies. Recording errors are possible and reading the station log can yield a lot of information if it indicates work being done on the river, obstacles or any other significant changes to the station.

2.2 WATER LEVELS AND THE DATABANK

The validated water level value entered into the databank is always the same as the raw recorded water level value.

This principle gives rise to some very specific adjustments. On a watercourse that is seasonally influenced (by vegetation growth for example) and given a sufficient number of gaugings, it is possible to put a correction of variable water levels into the databank, allowing us to keep a validated water level and rating curve.

If an obstruction temporarily disturbs the recording of a water level, with a calculable influence on it, it could be permitted to enter a corrected validated water level value as long as it is accompanied by code "8". If there is a long-term effect, then the rating curve will need to be changed.

Let's consider the case where a reach becomes completely dry or where natural discharge is interrupted for only a few days per year and then only once every n years: a brief increase of discharge followed by a drop in discharge during refilling. It is then necessary to create two stations: one with the observed discharges (and the validated water levels) and the other with reconstituted discharges, to use for statistical calculations where the discharge data has been smoothed and spread out over the period. This particularity should be signalled by comments for the two stations.

2.3 DISCHARGE EVALUATION

There should be an evaluation of the discharge values themselves.

A visual examination of the discharge hyrdrograph is a very useful exercise as it is easier for the hydrologist to detect an anomaly in a graphic than in a table of numbers.

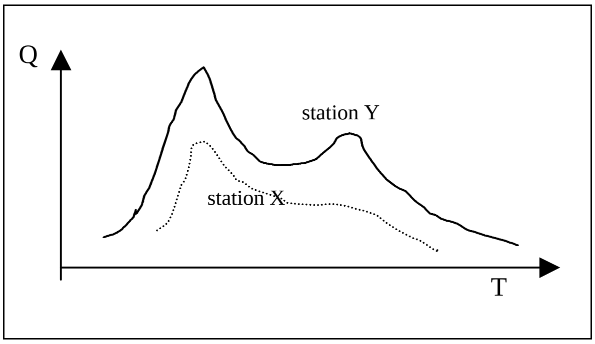
This examination should be done at different time intervals- monthly, quarterly, annually- and special attention should be paid to marks. The transition from one limnigraph to another, from one rating curve to another, from one calendar year to the next are all classic traps. The level of precision should obviously be adapted to the time scale used, instantaneous or daily.
Scale changes are sometimes necessary: a groundwater recession anomaly is difficult to detect on a monthly scale; a coding error is easier to notice over a short time period.
The alternate use of arithmetic and logarithmic scales will permit you to see many kinds of anomalies. The graphic possibilities that we have at our disposal today give us a golden opportunity to look at our old data where we will surely find a number of discreet but non-negligible errors.

In terms of managing low water conditions, a new problem is a rapid evaluation of data. To aid the hydrologist, we advise the calculation of recession curves from the last reliable data to validate the new data in real time. In areas that have been affected by draw-off, each case of water draw-off should be identified by type (retaken of irrigation after a rainy period, for example) which will complete the classic approach on natural recession.

2.4 COMPARATIVE DISCHARGE EVALUATION

Comparing data between stations is one good way to identify anomalies. Comparison does not mean similarity; it's in terms of major and cumulative differences that this analysis should be made.

The superimposition of hydrographs allows you to make simultaneous visual evaluation. The HYDRO databank authorises intensive use of this faculty with the possibility of a time lag scale.



simple test often used to judge if there is a problem with a station is called double mass curve. You graph the cumulative values of daily discharges for station Y that you want to evaluate against the same values for reference station X. A break or discrepancy in the one of the curves is a sign that one of the stations underwent a sudden or progressive change at a certain date. (This technique can also be used with flood water levels.)

It preferable to use the residual mass curve method which consists of two series X and Y linked by a single correlation Y = aX + b which defines the curve of cumulative residuals.

$$\mathbf{Ri = \Sigma \in i}$$
and
$$\mathbf{Yi = aXi + b + \in i}$$

If the curve Ri exceeds the limits of the confidence interval, there can be discontinuity and i provides us its presumed date. This method is available in the HYDRO databank under the heading CUMUL.

Another universal test consists of drawing the distribution of stations in a given area identified by the following co-ordinates:

- abscissa: logarithm of drainage basin areas
- ordinate: runoff

The examination of the distribution of points allows us to identify the anomalies. The same graph with QIX and log S is equally instructive.
This test is also available in the HYDRO databank under the heading "ZONAGE".

The use of stations located at a confluence of two streams can also allow you to identify anomalies: if the sum of the two discharges is greater than the total discharge downstream, a close analysis of the three discharges is in order, either their respective rating curves or their limnographs.

Likewise, verification of time lags upstream and downstream can cause problems if the inversion is constant or systematic for a given frequency.

If the setting up a permanent evaluation system for the station seems excessive, self examination of the station is nonetheless imperative.

Anomalies observed in the area of discharge values go back to initial data: water levels, gaugings and rating curves.

3 VALIDATION

It is after the evaluation that the validation is done. If production of good preliminary data is possible in a short time, you should still recognise that the validation of the data must be done with perspective and without haste.

Certain verification techniques mentioned earlier need ten years of data to be implemented properly.

It's not that this step should be put off indefinitely but a definitive value is never the current one.

This is why it is necessary to continue with overall revisions of historical data, taking advantage of the latest computer and graphic technology. Erroneous historical values in a long series will, if not adjusted, undermine statistical hydrology variables. A missing piece of data from extreme situation can have an even more dangerous effect on the eventual statistical validation of a phenomenon.

The monograph

The monograph consists of a written analysis of the past 10-15 years operation of a measuring station, including all the measurement data, gaugings, hydraulic characteristics of the site, etc. This is done methodically and calmly without imposed time constraints and it should always result in:

- readjustment of values, as necessary, even in supposedly well known discharge ranges
- the acquisition of the necessary elements for synthesis (frequency of rating curve shift or dispersal) that will be useful for the future
- consolidation of past results to better grasp future operational organisation.

The main French and International Standards concerning the discharge gauging in open channels

ISO 9555-1-4	Discharge gauging in open-channels - Dilution methods for a permanent flow
ISO 748-1997	Discharge gauging in open-channels : Velocity - area method
ISO 1100/1-1981	Discharge gauging in open- channels - Part 1: Installation of a gauging station
ISO 1100/2-1982	Discharge gauging in open-channels - Part 2 : Establishing the relation water level - discharge
ISO 772-1978	Discharge gauging in open-channels - Glossary and symbols - billing edition
ISO 1070 - 1973	Discharge gauging in open-channels - Slope area method
ISO 1088 - 1973	Discharge gauging in open-channels - Velocity area method, data checking
ISO 1438 - 1975	Discharge gauging in open-channels - Sharp-crested weir
ISO 1438/1 - 1980	Discharge gauging in open-channels - Sharp-crested weir
ISO 2425 - 1974	Discharge gauging in tide influence channels. Amendment 1 - 1982
ISO 2537 - 1974	Discharge gauging in open-channels - Propellers and buckets current meter
ISO 3454 - 1975	Discharge gauging in open-channels - Sounding and suspension devices
ISO 3455 - 1976	Current meter calibration
ISO 3846 - 1977	Discharge gauging in open-channels - Weir measuring
ISO 4359 - 1983	Discharge gauging in open-channels - rating flume measuring
ISO 4360 - 1979	Discharge gauging in open-channels - Weir measuring
ISO 4366 - 1979	Echo-sound depth measuring
ISO 4369 - 1979	Discharge gauging in open-channels - moving boat method
ISO 4373 - 1979	Discharge gauging in open-channels- Water level equipment
ISO 4374 - 1982	Discharge gauging in open-channels - Weir measuring
ISO 4377 - 1982	Discharge gauging in open-channels - Weir measuring
ISO 6416 - 1993	Discharge gauging in open-channels - Ultrasound method
ISO/TR 7178-1983	Study of the global error in velocity-area measuring method

ANNEXES , BIBLIOGRAPHY

Available only in the French version